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DECK WETNESS AND EXTREME MOTIONS EXPERIMENTS: AN INVESTIGATION INTO ESTABLISHING RELIABLE STATISTICS FOR RARE EVENTS

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P Crossland
A R J M Lloyd

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February 1990

DECK WETNESS AND EXTREME MOTIONS EXPERIMENTS: AN INVESTIGATION INTO ESTABLISHING RELIABLE STATISTICS FOR RARE EVENTS.

By

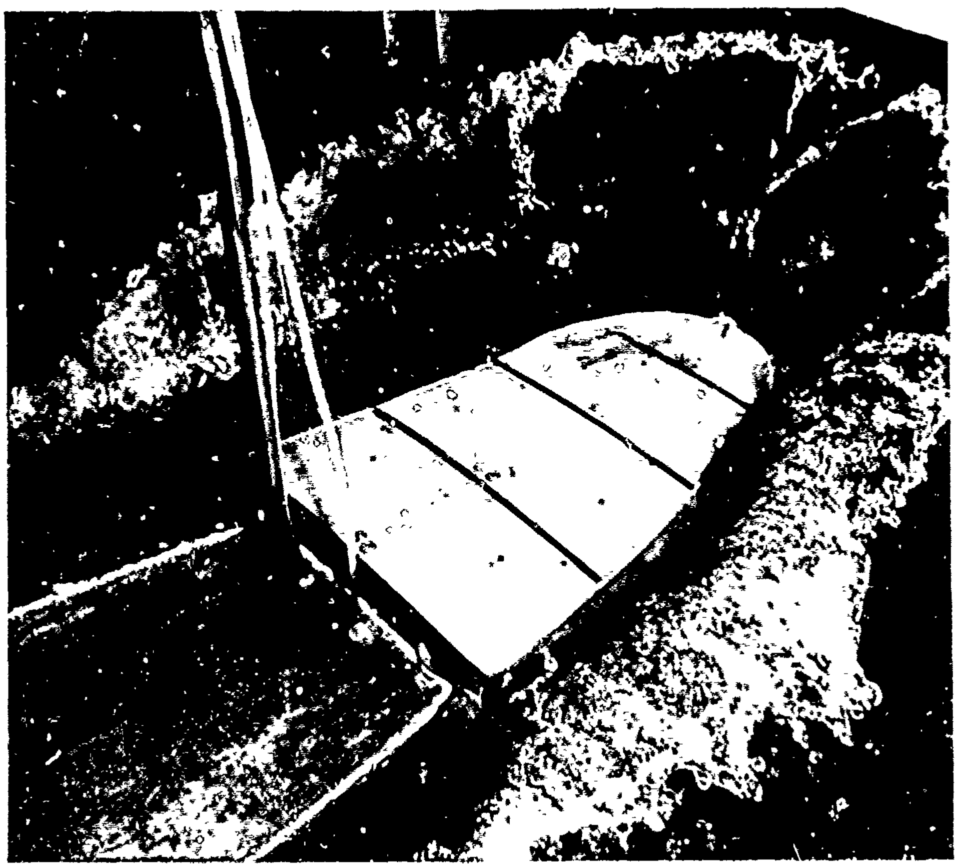
F Crossland
A R J M Lloyd

Summary

Experiments to establish reliable statistics for rare events such as deck wetness have been carried out at Haslar. A model of the S-175 container ship was tested at one speed in irregular head waves (one wave spectrum, different time histories).

The resul ·est that a minimum total run length of 200 model lengths is required a reasonable reliable estimate of the deck wetness frequency . oh--ined. Three hundred would represent good practice.

Admiralty Research Establishment
Haslar Gosport Hants PO12 2AG



Contents

Notation

a_0	Wave amplitude	(metres)
B	Midships beam	(metres)
C_b	Block coefficient	
C_m	Midships area coefficient	
FP	Forward perpendicular	
g	Acceleration due to gravity	(m/s^2)
GM	Metacentric Height	(metres)
$H_{1/3}$	Significant wave height	(metres)
KG	Height of Vertical centre of gravity above keel.	(metres)
L	Waterline length	(metres)
L_T	Length of tank	(metres)
lcb	Longitudinal centre of buoyancy	(per cent L aft of midships)
M	Displacement	(tonnes)
N	Run number	
N_w	No of wettings	
r	Relative motion	(metres)
s	Absolute motion	(metres)
T	Midships draught	(metres)
T_0	Modal period	(seconds)
T_ϕ	Natural roll period	(seconds)
ω	Wave frequency	(rads/s)

DECK WETNESS AND EXTREME MOTIONS EXPERIMENTS: AN INVESTIGATION INTO ESTABLISHING RELIABLE STATISTICS FOR RARE EVENTS

By P Crossland and A K J M Lloyd

1. OBJECTIVES

The purpose of this report is to describe in detail the experiments carried out at the Admiralty Research Establishment at Haslar to record frequency of deck wetness and to obtain statistical information about extreme motions. The experiments are part of an international collaborative exercise designed to obtain a more soundly based standard for experiments on rarely occurring events such as deck wetness, slamming, etc.

It is hoped to obtain a better understanding about the process of deck wetness by analysis of the time histories.

2. INTRODUCTION

One of the factors of seakindliness is deck wetness. In extreme sea conditions the frequent shipping of water onto the bow of a vessel causes damage to fittings exposed on the forecastle and in severe conditions, (see Frontispiece), it may lead to capsize. It is necessary to be able to assess the frequency and severity of deck wetness for a particular hull form in a particular sea condition at the design stage and compare results with suitable criteria (Andrew and Lloyd, Reference 1).

At the design stage, computer programs such as the PAT-86 suite of seakeeping computer programs (Reference 2) are employed to calculate the notional rms relative motion at the bow (ie taken from the calculation of absolute motion and undisturbed wave at the bow). Correction factors are used to account for the 'swell up' at the bow (References 3 and 4). The computer program predicts, though not very well, when the water rises above the level of the deck (freeboard exceedance). However, not all freeboard exceedances result in deck wettings. At the moment it is not possible to predict deck wetness frequency correctly using conventional strip theory computer programs.

An alternative is to carry out a series of experiments to measure deck wetness frequency on a model. Lloyd (Reference 5) describes, extensively, a set of experiments to determine the effect of above water bow form on deck wetness in head seas. A total run length of at least one hour at full-scale was available for analysis for each bow considered. However, one of the problems involved in assessing the relative merits of different hull forms when considering rarely occurring events such deck wetness is the determination of how many tank runs (with the same wave spectrum but different wave time histories) are needed to establish wetness statistics with any degree of reliability. It is desirable to carry out a minimum number of tank runs yet still achieve results with a certain degree of statistical reliability.

Recommendation 2.2.4 by the 18th ITTC Seakeeping Committee (Reference 6) called for a study aimed at establishing a more soundly based standard for experiments on rarely occurring events such as deck wetness. The approach adopted was to organise a series of comparative experiments to measure deck

wetness. Twelve Tanks throughout the world agreed to test the S-175 container ship in a specified ITTC two parameter wave spectrum and record the average deck wetness frequency experienced at one speed in head waves. All the information has been collated and analysed by ARE (Haslar) and will be published in due course. The purpose of this report is to describe experiments carried out by Haslar as their contribution to the collaborative experiments.

3. EXPERIMENTS

The experiments were conducted at ARE (Haslar) in April 1989 in No 1 Ship Tank. The PDP 11 computer was used to acquire and process the data using DATS software developed by Prosig Computer Consultants Ltd.

3.1 Model

The GRP Model, DRC, was a 3.5 metre unappended model (1/50th scale) of the S-175 container ship. The dimensions are given in Table 1. The model forecastle was decked at the forecastle deck side line with bulwarks fitted, as shown in the body plan in Figure 1. Adequate freeing ports were provided in the bulwarks to allow efficient water drainage. The model was towed using the carriage. The towing arrangement shown in Figure 2 restrained the model in surge and yaw but it was allowed to heave, pitch, sway and roll.

3.2 Model Instrumentation

3.2.1 Ship Motions and Waves

Absolute vertical displacement at the stem head and 0.15L aft of the FP was measured using string and potentiometer systems. The wave time histories were measured at two positions:

a. Five metres from the wave maker about the centre line of the tank (measuring actual wave time history).

b. One metre to the port side of the FP of the model (measuring encountered wave time history).

Both time histories were measured using resistance wave probes.

3.2.2 Wetness

Deck wetness was monitored using resistance probes mounted inverted on the centre line of the forecastle of the model at the FP and 0.1L aft of the FP (see Frontispiece). This gave time histories of deck wettings at these two positions. The wetness events were also monitored using video recorders mounted at a 3/4 position aft of the forecastle and at a position on the port side giving a profile view. Markings were painted on the forecastle and on the bow to aid visual recording of the wetness events (see Figure 3 and Reference 7).

3.2.3 Relative Motion

The model was fitted with resistance wires to measure relative motion at the stem head and 0.15L aft of the FP (Reference 8). The relative motion

probes extended below the keel but not above the freeboard. The extent of the probes is shown in Table 2 and Figure 3.

The sign conventions adopted are shown in Table 3.

All calibrations, carried out prior to the commencement of the experiment, were found to be linear to a satisfactory degree. The calibration coefficients are given in Table 3.

3.3 Experiment conditions

The experiment conditions were:

Froude Number $U/\sqrt{gL} = 0.275$

Long crested irregular head waves with ITTC two parameter wave spectrum defined by:

$$S(\omega) = A/\omega^5 \exp(-B/\omega^4)$$

with

$$A = \frac{487.3\, H_{1/3}}{T_0}, \quad B = \frac{1949}{T_0}$$

and

$$H_{1/3}/L = 0.045$$

$$T_0 \sqrt{g/L} = 3.5$$

Long waves in No 1 Ship Tank suffer from shallow water effects. Lloyd and Fryer (Reference 9) describe a technique which corrects for these effects. Thus, the waves generated in No 1 Ship Tank for the purpose of this experiment are not from an ITTC two parameter spectrum but a slightly distorted spectrum. Figure 4 shows the ITTC spectrum and the specified spectrum (corrected for long wave shallow water effects). The wave conditions for model and ship are shown in Table 4. The generation of the random wave is described by Fryer in Reference 10. He includes details of wave generation, beach reflections and the useful length of the tank when generating random waves. Software has been developed by Gilbert (Reference 11) for the wavemaker in No. 1 Ship Tank to generate the required random wave and supply the user with the usable run length. The software enabled a different time history to be used for each tank run and this was a necessity for the experiment.

3.4 Preliminary Experiments

Calm water runs were carried out to measure the bow wave elevation using the relative motion probes and also to measure the trim and sinkage of the model at the running speed for the wave experiments.

4. DATA ANALYSIS

Data were acquired from all of the measuring devices in a multiplexed form, which had to be demultiplexed and multiplied by a calibration coefficient. Selected time histories were examined and a spectral plot was made of the actual wave time history to ensure that the correct wave condition had been achieved before accepting the run as valid. A note was made of the number of deck wettings observed and all data were then stored in the multiplexed form for further analysis at a later date.

Specially written software was used to complete the analysis. Program CLIPED was written to restore the peaks and troughs to the relative motion time histories caused by the fact that the relative motion probes did not extend beyond the freeboard and not far enough below the keel. The method is similar to that employed by Lloyd in Reference 5. Results included a detailed look at the wave time histories, deck wetness severity and analysis of how many tank runs were needed to get reliable statistics.

The final results also included :

a. Calm water runs.

b. Amalgamated for all tank runs:

(1) Significant wave height and modal period of achieved wave condition.

(2) Mean and RMS motions (absolute and relative) at the stem head and 0.15L aft of the FP.

(3) Comparison of experimental values of RMS motions with those calculated in PAT-86.

(4) Probability distributions of peaks and troughs of motions and waves and comparison with the Rayleigh formula.

c. For each individual run. Records of the number of deck wetting events at the FP and 0.1L aft of the FP.

5. RESULTS

5.1 Calm Water

The experiments showed that the bow wave was an extremely local effect ie the water surface remained virtually undisturbed until about a centimetre forward
of the stem head. However, the probes were calibrated to measure the much larger motions in waves so the calm water results are not very reliable.

5.2 Waves

Figure 5 shows the specified and actual spectra for the experiment. The spectra agree well in the longer waves and waves close to the modal period. However, there is some scatter at the higher frequencies, but the results are still acceptable. The measured significant wave height and modal period are compared with the desired values in Table 4.

Figure 6 shows a graph of the probability of wave peaks and troughs exceeding various levels amalgamated over all valid tank runs, for measurements made by both the carriage and tank wave probes. The solid line represents theoretical results based on the Rayleigh distribution using the measured RMS wave elevation (Reference 5). The experiment results show that high peaks are more likely and deep troughs are less likely to occur than would be predicted by the linear theory. This is not totally unexpected, since for sea conditions as extreme as the one used in this experiment non-linear effects are likely to be present. An example of these Stokes waves is shown in Reference 12.

5.3 Motions in long crested irregular waves

The RMS motions are shown in non dimensional form in Table 6 and compared with the PAT-86 predictions, (discussed further in 5.5). The non dimensional groups are given in Table 5. Figures 7 and 8 show the probability of the motion amplitudes exceeding various levels compared with the Rayleigh formula (solid line).

Figure 7 shows absolute motion at the two stations. Again, the motions follow a Rayleigh distribution closely except at the larger amplitudes. This may be associated with the non linearities in the motion responses, but it also, no doubt, a function of the discrepancies already noted for the waves in Figure 6.

Figure 8 shows relative motion at the two stations. The experiment results match the theory much less well than in Figures 6 and 7. This is presumably due to the bow swell up which is less significant at 0.15L aft of the FP. The results show that freeboard exceedance (and deck wettings) are much more likely than the Rayleigh formula would suggest. Conversely, keel emergence and slamming are less likely. Also shown in Figure 8 are the limits of the relative motion probes. Peak values outside these limits have been reconstructed using the CLIPED program described in section 4. There is some evidence of discontinuities in the results at these limits suggesting that the restored peaks are not quite correct.

5.4 Sample time histories

Figures 9-10 show sample time histories taken from the experiment. The blue line represents the motion (or waves) and the red line gives an indication of deck wetness incidence. The actual height of the line is not a very good indication of deck wetness severity because the measurement technique was not sophisticated enough to distinguish between a solid lump of water or a large 'splash' of water on the deck. It was hoped that these time histories would provide an insight into the process of deck wetness. More analysis will be done at a later stage.

5.5 Comparisons with predicted results

The suite of seakeeping computer programs at ARE (Haslar) was used to predict the RMS motions and motion spectra at the two positions. The actual input wave spectrum was that obtained from the analysis of the wave time histories used in the experiment. The program takes no account of the stem rake when calculating relative motion and this may be the cause of some of the errors in the prediction.

Figure 11 show the comparison between the measured and predicted absolute motion spectra. The predicted absolute motion spectra seems to be too low, especially at or around the modal period.

Figures 12 show the relative motion spectra, the prediction is much lower ,by up to 50 per cent in some cases, and it seems to get worse further aft. The conclusions drawn from the Figures are reflected in comparisons of experimental and predicted values for RMS motions, shown in Table 6. Generally, RMS absolute motions are under predicted by about 8 per cent and relative motions by about 12 per cent. These discrepancies are probably due to :

a. The severe wave condition introducing non linearities.

b. The bow swell up not being predicted by PAT-86.

c. PAT-86 not taking into account the stem rake.

5.6 Wetness

Considering only those runs obtained in the correct wave condition, Table 7 shows that the observed deck wetness frequency for each run varied over a large range from 2 to 14. Table 7 also shows the results obtained in order and the running average non-dimensional wetness frequency as the experiment progressed.

If the experiment had been done in a different order different estimates of the running mean would have been obtained although the final result would have been the same. Figure 13 shows the running deck wetness frequency as a function of non-dimensional run length for 25 different run orders chosen at random. The broken lines represent 1.1 and 0.9 times the final average wetness frequency.

From Figure 13 we can recommend that a total run of 200 model lengths is required to give a reasonably reliable estimate of wetness frequency. Three hundred would represent very good practice. Even here there is a reasonable probability of the estimated wetness frequency being in error by more than
10 per cent.

6. CONCLUSIONS

This report has described an experiment to establish a more soundly based standard for experiments on rarely occurring events. The experiments at Haslar are part of a collaborative exercise with 12 tanks throughout the world. The results from the other tanks will be collated at a later stage. The model was tested in irregular head waves at a single speed using a different time history for each tank run. The deck wetness frequency was recorded as well as relative and absolute motion at the stem head and 0.15L aft of the FP.

The experiments show that the waves behave non linearly and as a result so do the motions. In addition, the non linearity is intensified in the case of relative motion because of the bow swell up. The theoretical predictions are quite good considering the severity of the wave condition.

7. RECOMMENDATION

The authors recommend that for the model of the S-175 container ship and the wave conditions generated in No 1 Ship Tank, experiments to measure rare events such as deck wetness and slamming should be run for at least 200 ship or model lengths. Three hundred would represent good practice. The question must be asked if this will be adequate ,or indeed too much, for other experimental conditions. It is impossible to set standard run lengths for all experimental conditions and so a method should be developed to analyse the results statistically as the experiments are carried out.

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Table 1

PRINCIPAL PARTICULARS OF SHIP AND MODEL

	Ship	Model
L (m)	175.00	3.50
B (m)	25.40	0.51
T (m)	9.50	0.19
M (tonnes)	24742.00	0.19
lcb (per cent L)	1.42	1.42
C_m	0.97	0.97
GM (m)	1.00	0.02
T_ϕ (s)	18.00	2.55
KG (m)	9.52	0.19

Table 2

EXTENT OF RELATIVE MOTION PROBES (for model)

Relative Motion	Freeboard	Maximum	Keel	Minimum
Stem head (m)	0.212	0.200	- 0.190	- 0.240
0.15L aft FP(m) (stbd/port)	0.180	0.150	- 0.190	- 0.230

Table 3

SIGN CONVENTION AND CALIBRATION COEFFICIENTS

Probes	Sign Convention	Calibration Coefficient (Volts/metre)
Wave probes:	Positive wave troughs	
Tank		- 0.0283
Carriage		- 0.0294
Potentiometers:	Positive bow down	
Stem head		- 0.0375
0.15L aft FP		- 0.0373
Wetness probes:	Positive water on deck	
FP		0.0175
0.1L aft FP		0.0174
Relative motion:	Positive bow down	
Stem Head		0.0343
0.15L (port)		0.0307
0.15L (stbd)		0.0350

Table 4

WAVE CONDITIONS FOR SHIP AND MODEL

	Ship	Model	
		desired	achieved
$H_{1/3}$(m)	7.88	0.1575	0.1643
T_0 (s)	14.78	2.09	2.05

Table 5

NON DIMENSIONAL GROUPS

Quantity	Non Dimensional Group
Absolute motion	s/L
Relative motion	r/L
Frequency	$\omega\sqrt{L/g}$
Wave amplitude	a_ζ/L
Modal period	$T_0\sqrt{g/L}$
Spectral ordinate	$S(\omega)/L^2\ \sqrt{g/L}$
Run length	$N_R\ L_?/L$
Wettings	N_W/Run length

Table 6

RMS MOTIONS IN IRREGULAR WAVES

Motion	PAT-86	Experiment
s/L at stem head	0.026	0.028
s/L 0.15L aft FP	0.022	0.022
r/L at stem head	0.029	0.032
r/L 0.15L aft FP	0.024	0.029

Table 7

DECK WETNESS FREQUENCY

Run Number	Number of Wettings	Non dimensional run length	Wettings per model length	Running mean
1	10	18.4	0.543	0.543
2	12	36.8	0.652	0.597
3	11	55.3	0.597	0.597
4	6	73.7	0.326	0.529
5	12	92.1	0.652	0.554
6	13	110.5	0.706	0.579
7	14	128.9	0.760	0.605
8	8	147.3	0.434	0.584
9	8	165.8	0.434	0.567
10	13	184.2	0.706	0.581
11	7	202.6	0.380	0.563
12	6	221.0	0.326	0.543
13	10	239.4	0.543	0.543
14	9	257.8	0.489	0.539
15	8	276.3	0.434	0.532
16	4	294.7	0.217	0.512
17	8	313.1	0.434	0.508
18	11	331.5	0.597	0.513
19	2	349.9	0.109	0.492
20	8	368.3	0.434	0.489
21	4	386.8	0.217	0.476
22	7	405.2	0.380	0.471
23	13	423.6	0.706	0.482
24	8	442.0	0.434	0.480
25	5	460.4	0.271	0.471
26	14	478.8	0.760	0.482

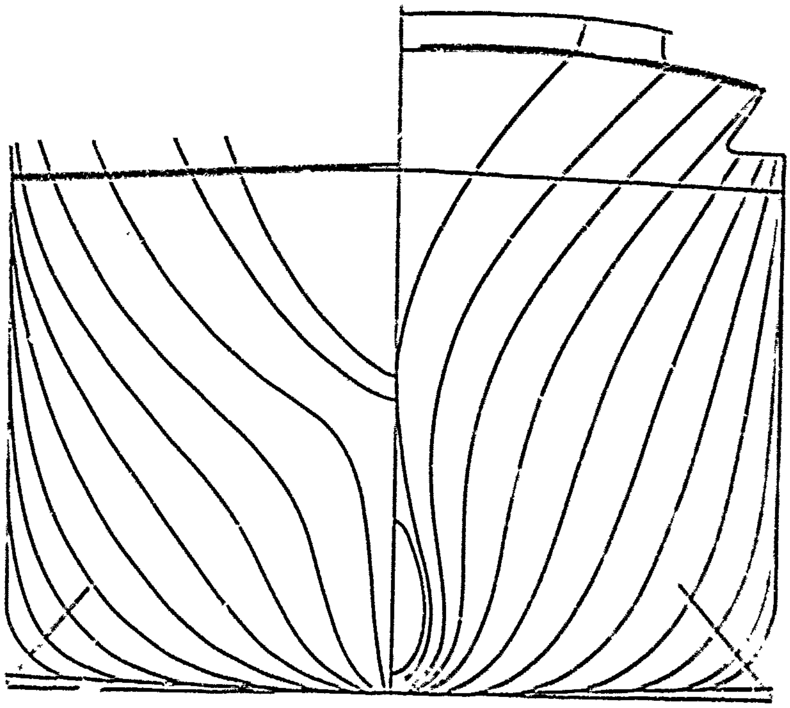


Figure 1

BODY PLAN

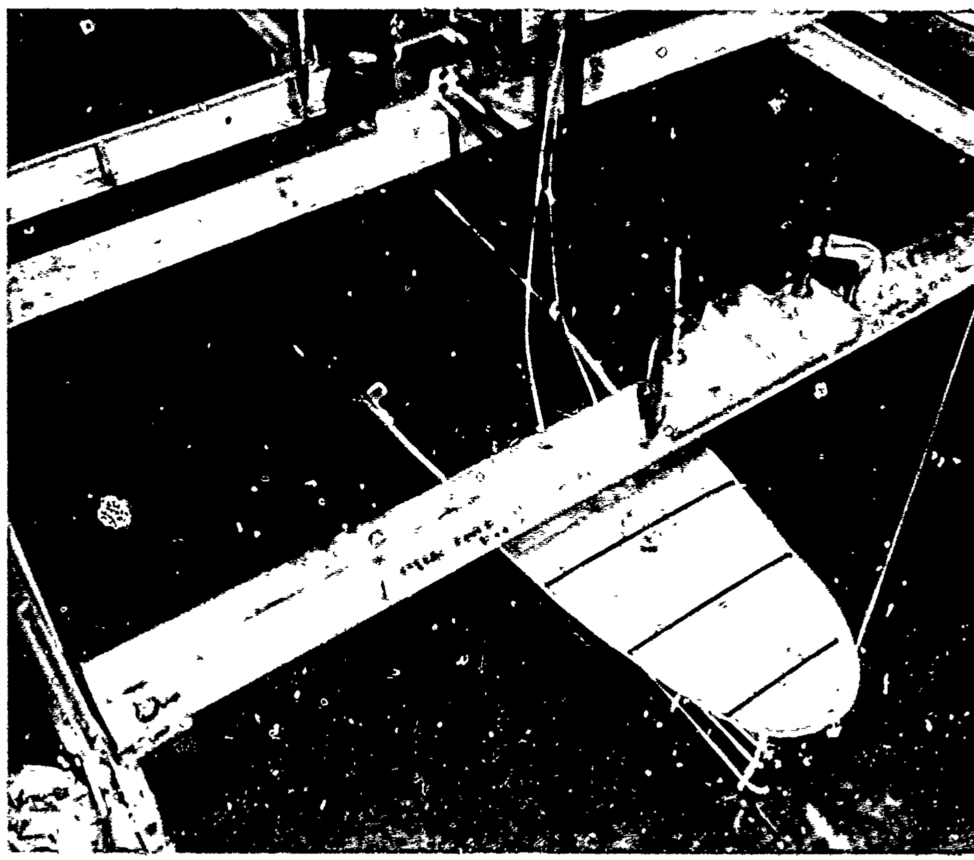


Figure 2

TOWING ARRANGEMENT

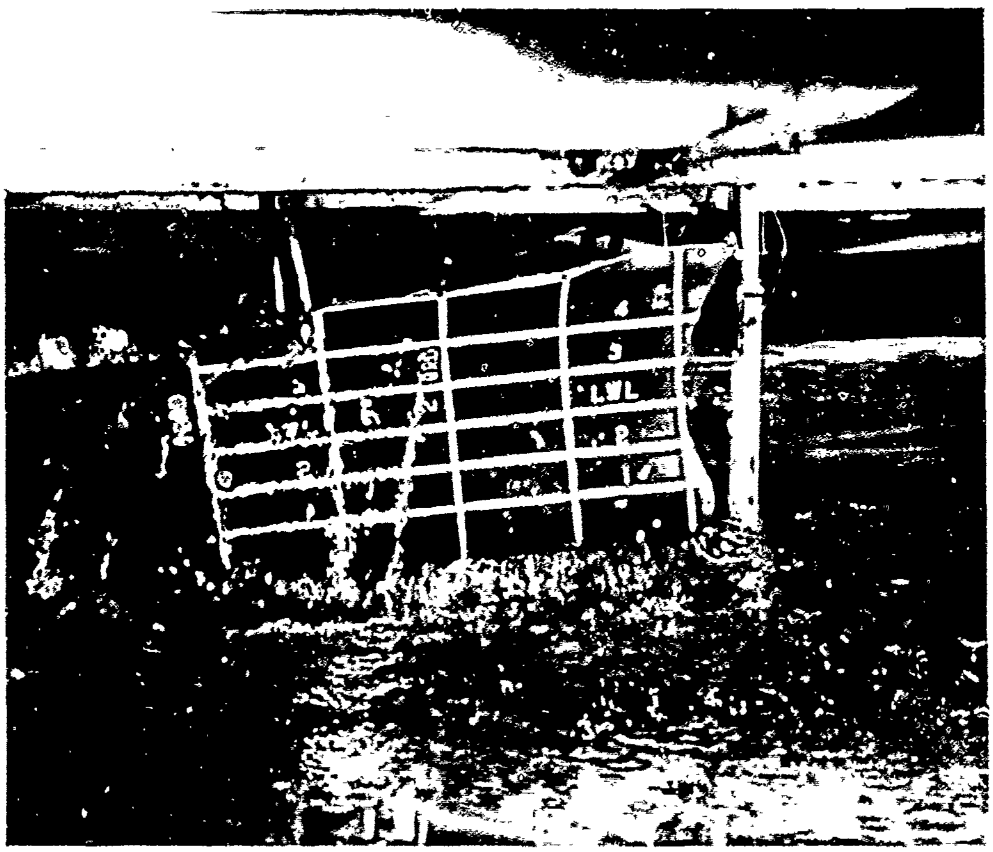


Figure 3

BOW MARKINGS

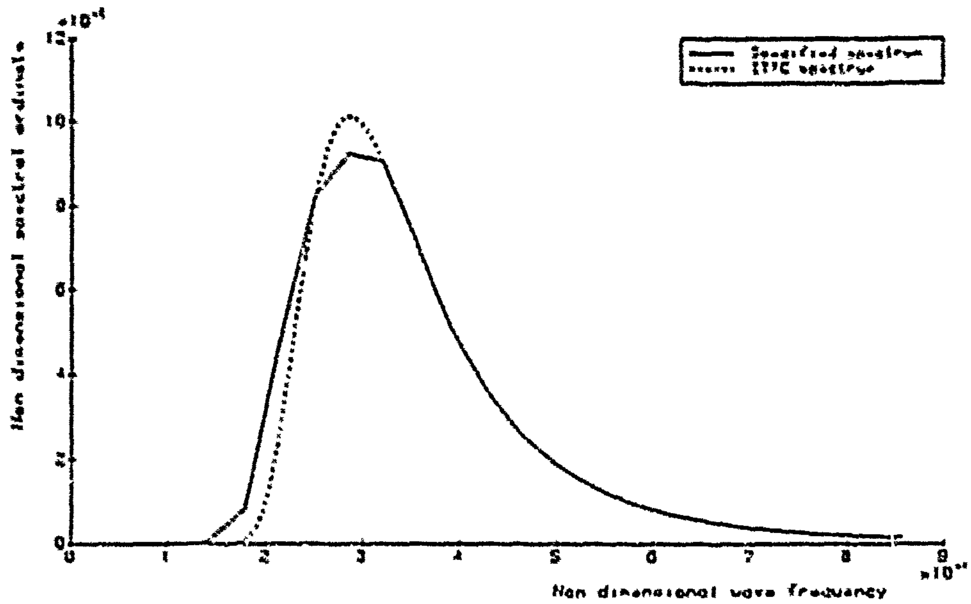


Figure 4

WAVE ENERGY SPECTRUM CORRECTION

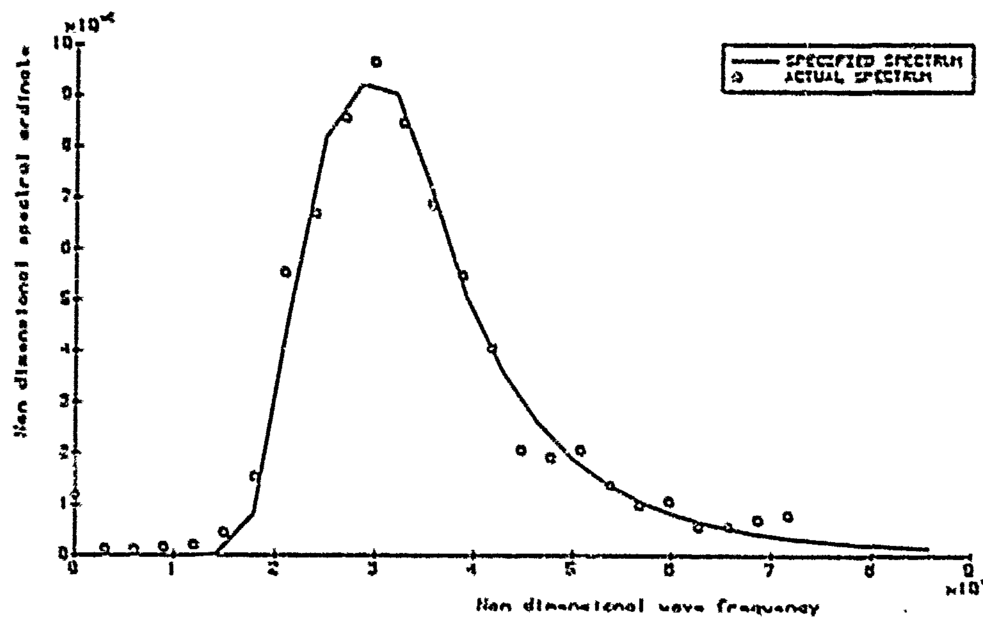
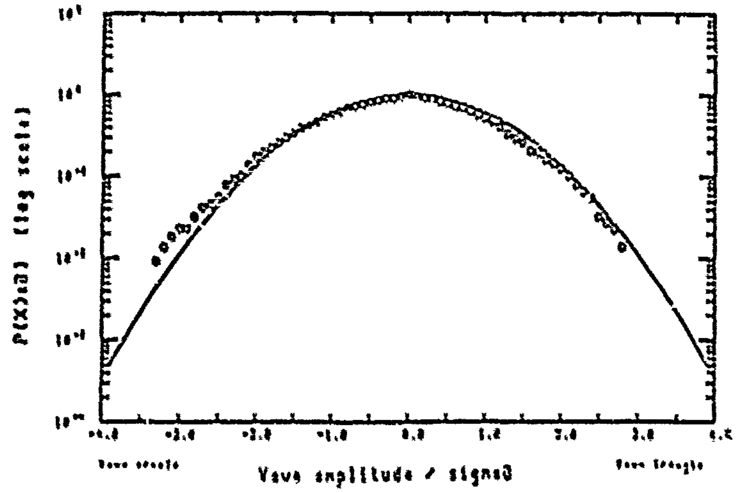
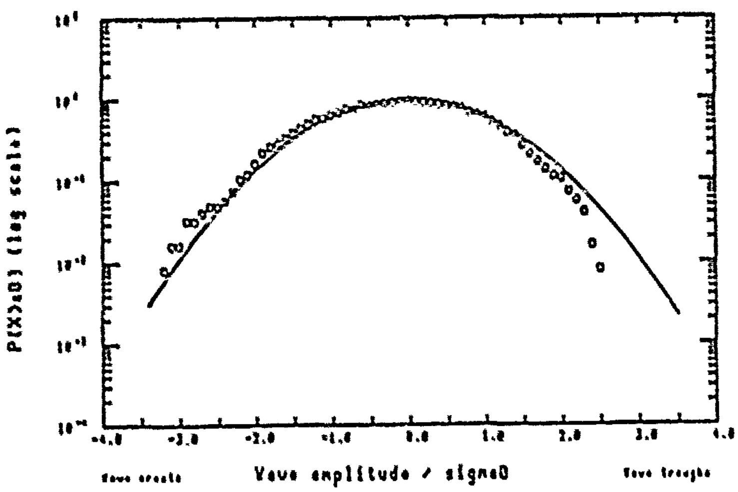


Figure 5

WAVE SPECTRA



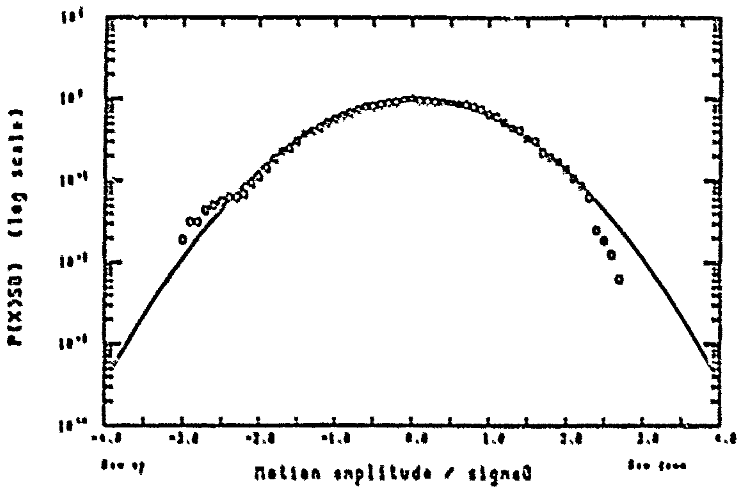
a. CARRIAGE WAVE PROBE



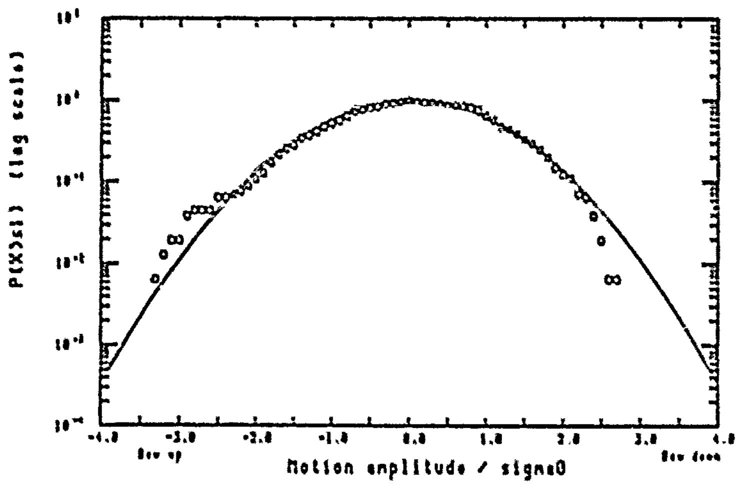
b. TANK WAVE PROBE

Figure 6

PROBABILITY DISTRIBUTION OF WAVE PEAKS AND TROUGHS



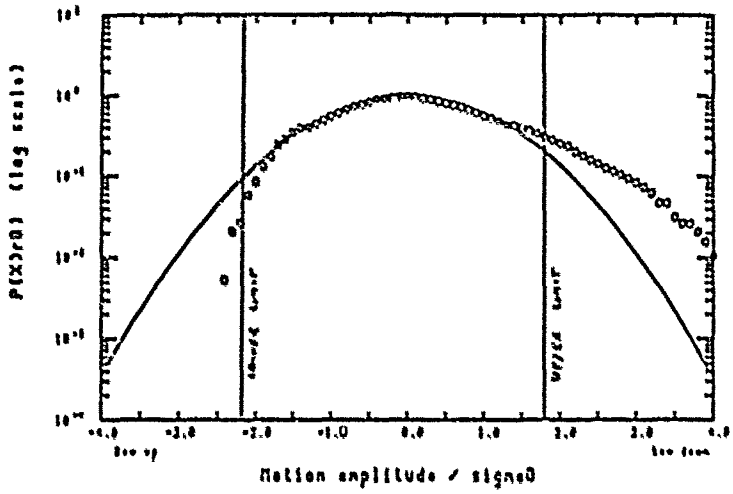
a. <u>ABSOLUTE MOTION AT THE STEM HEAD</u>



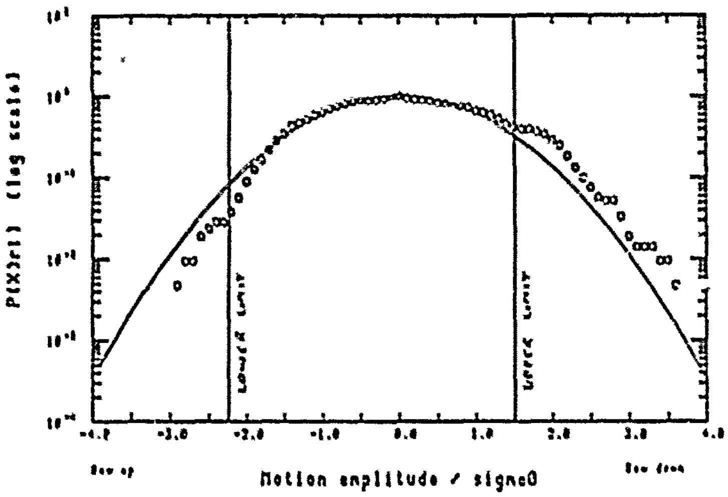
b. <u>ABSOLUTE MOTION 0.15L AFT FP</u>

Figure 7

<u>PROBABILITY DISTRIBUTION OF ABSOLUTE MOTION</u>



a. RELATIVE MOTION AT THE STEM HEAD



b. RELATIVE MOTION 0.15L AFT OF FP

Figure 8

PROBABILITY DISTRIBUTION OF RELATIVE MOTION

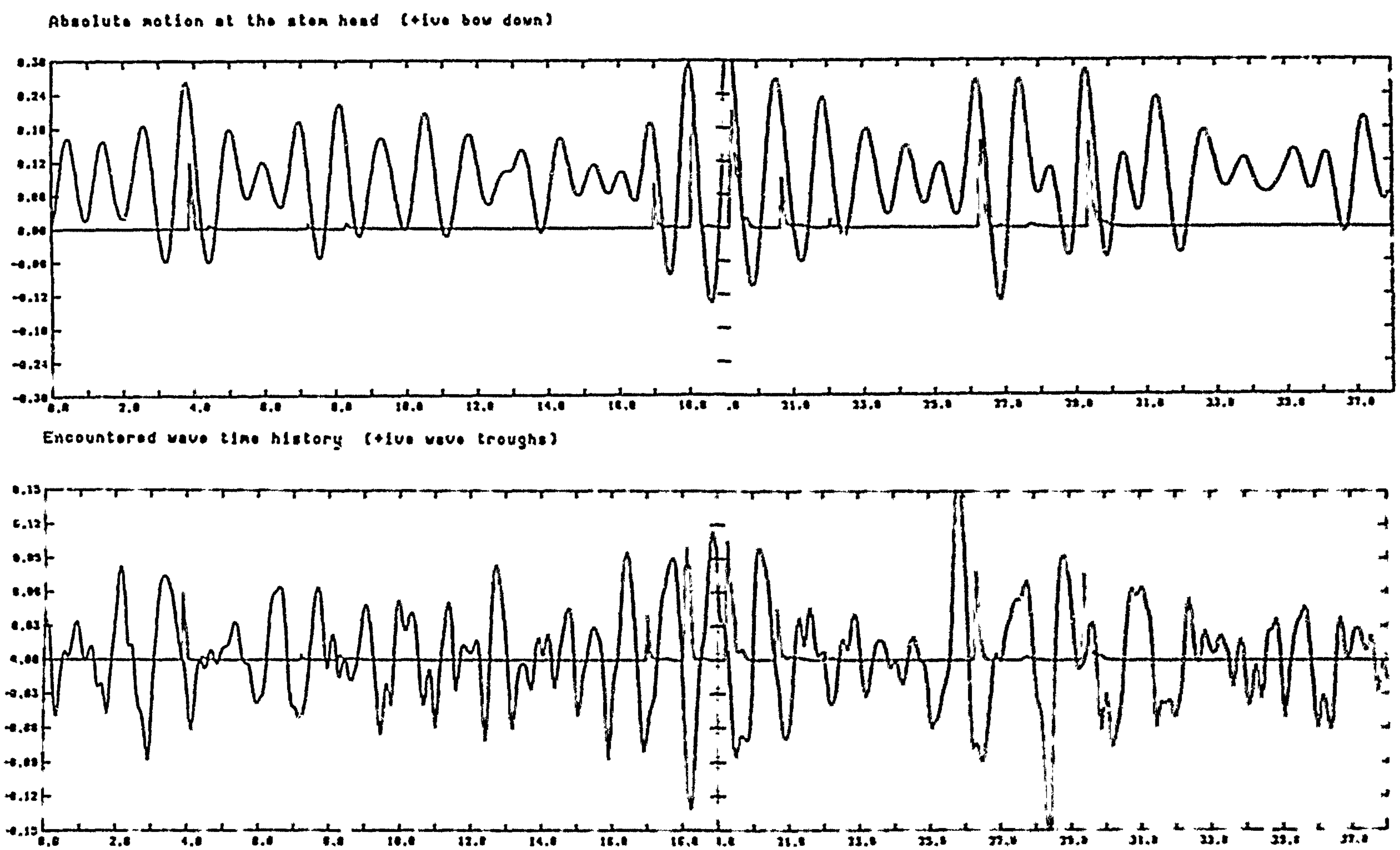


Figure 9

SAMPLE TIME HISTORIES

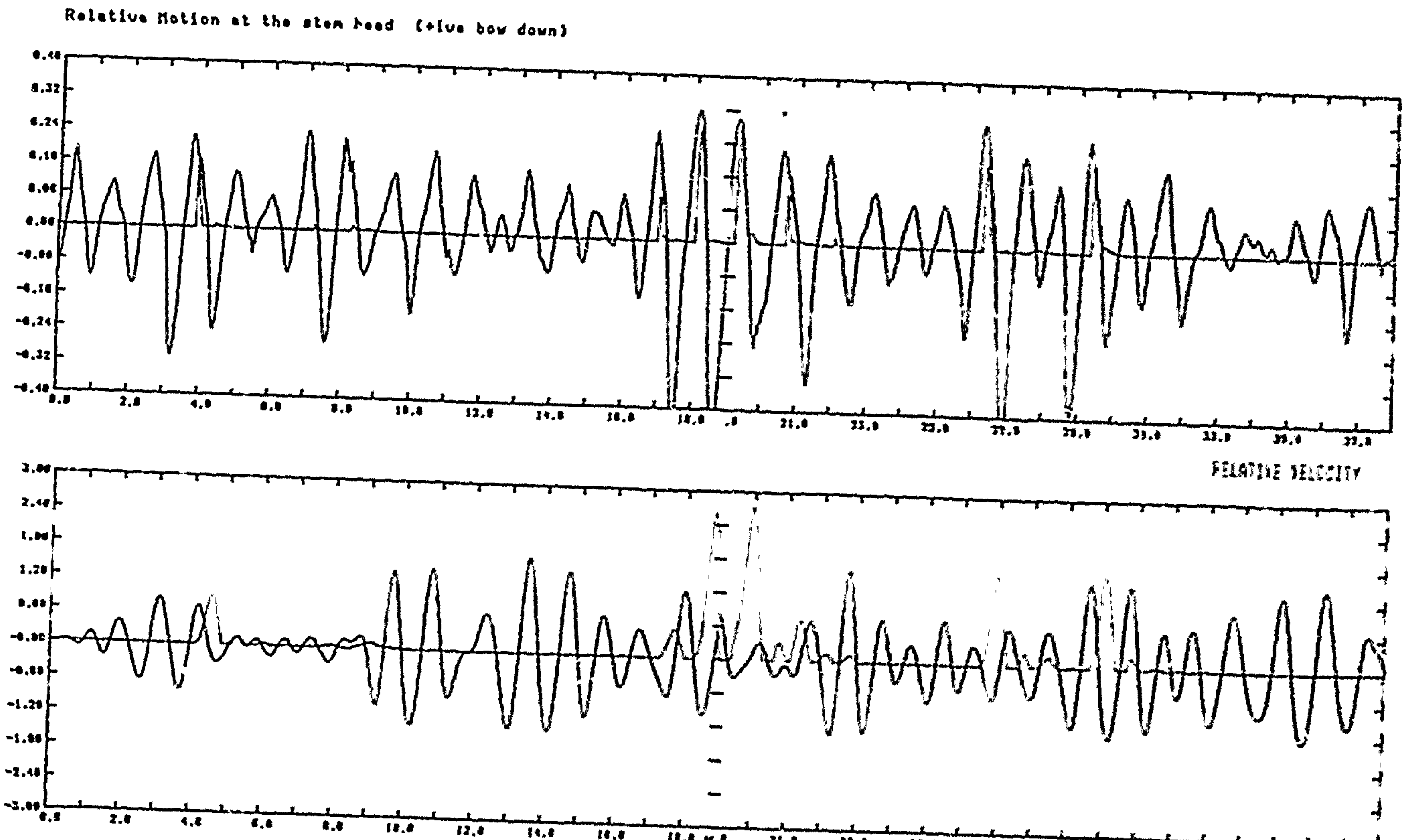
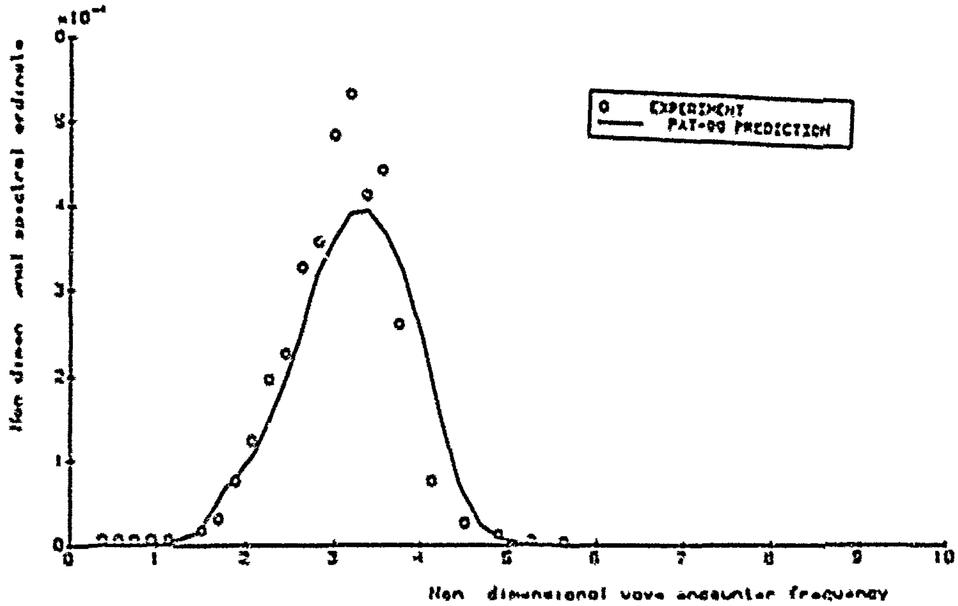
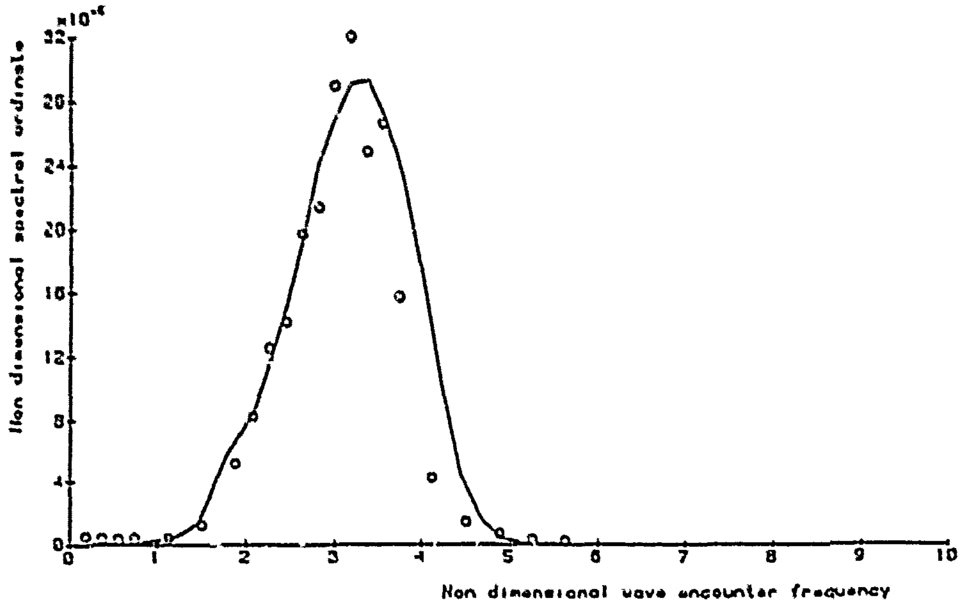


Figure 10

SAMPLE TIME HISTORIES



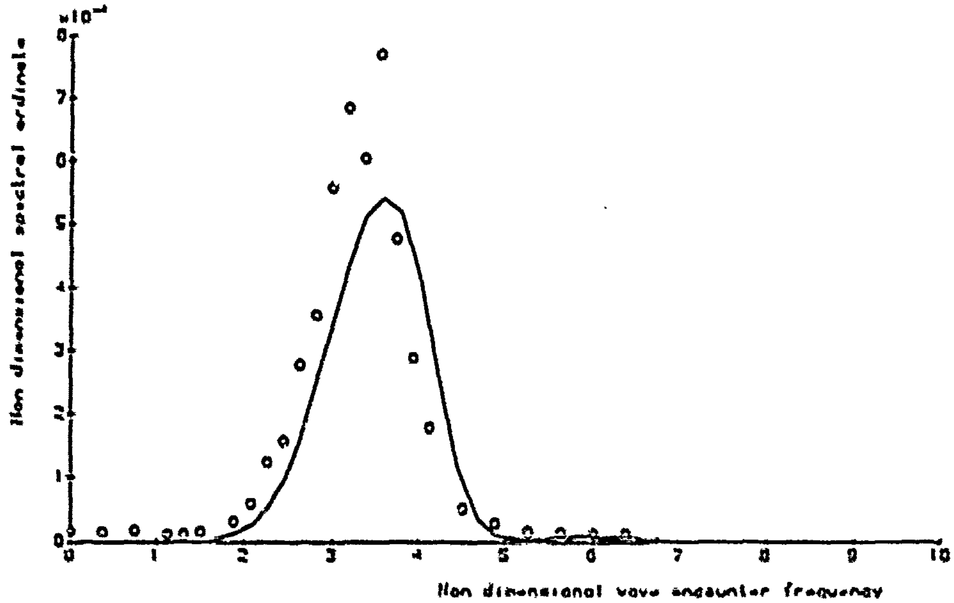
a. ABSOLUTE MOTION AT STEM HEAD



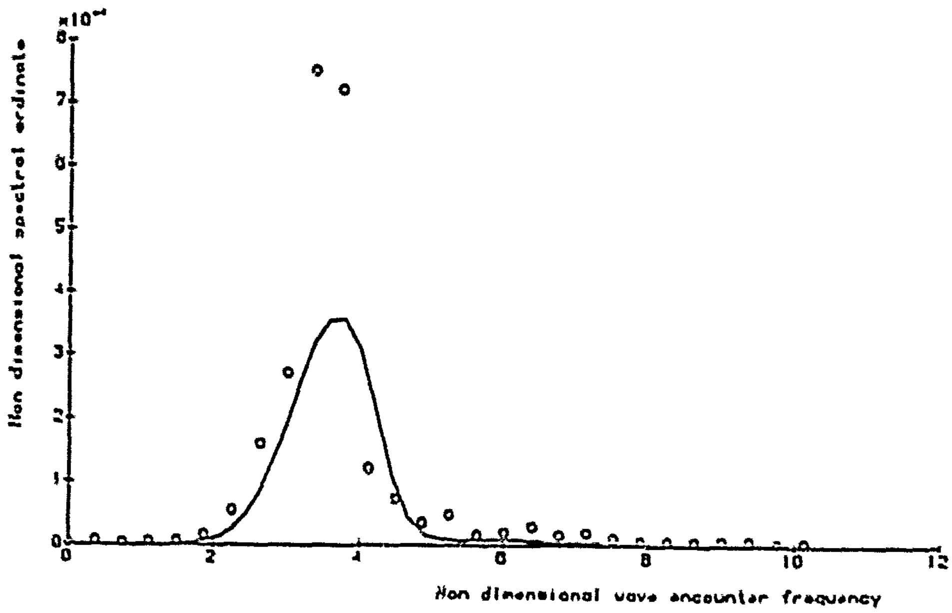
b. ABSOLUTE MOTION 0.15L AFT STEM HEAD

Figure 11

MEASURE AND PREDICTED ABSOLUTE MOTION SPECTRA



a. RELATIVE MOTION AT THE STEM HEAD



b. RELATIVE MOTION 0.15L AFT STEM HEAD

Figure 12

MEASURED AND PREDICTED RELATIVE MOTION SPECTRA

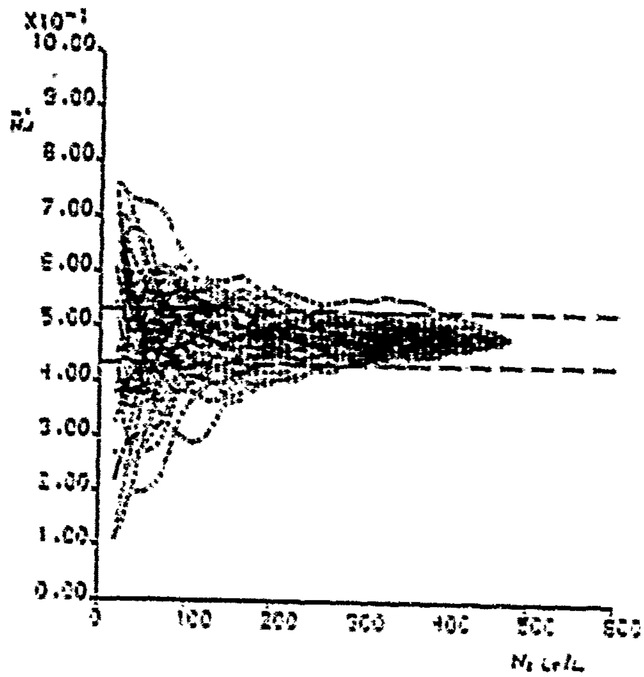


Figure 13

RUNNING AVERAGE WETNESS FREQUENCY

DOCUMENT CONTROL SHEET

Overall security classification of sheet: UNCLASSIFIED

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification, eg (R), (C) or (S).)

1. DRIC Reference (if known)	2. Originator's Reference ARE TR90301
3. Agency Reference	4. Report Security Classification UNCLASSIFIED
5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location ADMIRALTY RESEARCH ESTABLISHMENT HASLAR, GOSPORT, HANTS, PO12 2AG
5a. Sponsoring Agency's Code (if known)	6a Sponsoring Agency (Contract Authority) Name and Location

7 Title
DECK WETNESS AND EXTREME MOTIONS EXPERIMENTS:
AN INVESTIGATION INTO ESTABLISHING RELIABLE
STATISTICS FOR RARE EVENTS

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers) Title, place and date of conference

8. Author 1, Surname, initials	9a. Author 2	9b. Author 3, 4	10. Date	Refs
CROSSLAND P	LLOYD A R J M		2.90	

11. Contract Number	12. Period	13. Project	14. Other References

15. Distribution statement
UNLIMITED

Descriptors (or keywords)
SHIP MODEL, HULL FORMS, ITTC WAVE SPECTRUM
SLAMMING BOW MOTION

Abstract

Experiments to establish reliable statistics for rare events such as deck wetness have been carried out at Haslar. A model of the S-175 container ship was tested at one speed in irregular head waves (one wave spectrum, different time histories).

The results suggest that a minimum total run length of 200 model lengths is required before a reasonable reliable estimate of the deck wetness frequency can be obtained. Three hundred would represent good practice.